**Naval Surface Warfare Center**
**Carderock Division**
West Bethesda, MD 20817-5700

**NSWCCD-65-TR–2000/07** March 2000

Survivability, Structures, and Materials Directorate

Technical Report

# User's Guide for SPECTRA: Version 8.3

by

Robert W. Michaelson





NSWCCD-65-TR–2000/07 User's Guide for SPECTRA: Version 8.3

DEPARTMENT OF THE NAVY

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From: Commander, Naval Surface Warfare Center, Carderock Division
To: Commander, Naval Sea Systems Command (SEA 05R2)

Subj: PREDICTION OF EXTREME AND LIFETIME EXCEEDANCE PRIMARY HULL GIRDER BENDING LOADS

Ref: (a) Program Element 0603563NB, Reliability Based Design Criteria for Surface Ships, Project S2196-00, Subtask I-G for FY2000.

Encl: (1) NSWCCD-65-TR–2000/07, *User's Guide for SPECTRA: Version 8.3*

1. Reference (a) requested the Naval Surface Warfare Center, Carderock Division (NSWCCD) to document the SPECTRA computer program for predicting extreme and lifetime exceedance primary hull girder bending loads. Enclosure (1) contains the basic instructions for running SPECTRA program, with suggestions for suitable input data.

2. Comments or questions may be referred to Mr. Robert W. Michaelson, Code 651; telephone (301) 227-4200; e-mail, MichaelsonRW@nswccd.navy.mil.

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Enclosure (1)

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SPECTRA is a Windows-based computer program for predicting extreme and lifetime exceedance primary hull girder bending loads. Extreme loads can be used for reliability-based strength design criteria, and exceedance loads can be used for fatigue strength design criteria. Loads are calculated based upon ship geometry, the sea conditions, and operating characteristics of the ship as specified by the user. This User's Guide contains the basic instructions for running SPECTRA program, with suggestions for suitable input data.

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# Contents

## Administrative Information

The work reported herein was performed in the Structures and Composites Department (Code 65) of the Survivability, Structures, and Materials Directorate. This work was sponsored by the Naval Sea Systems Command under the direction of Mr. Jeffrey Hough (SEA 05R2). It is part of the Reliability Based Design Criteria for Surface Ships Task (PE63563N, Project S2196-00) and supports Subtask I-G.

## Acknowledgements

The SPECTRA computer program represents many years of data gathering, processing, and formulating ship model tests and sea trials. This work began years before the author began working at Carderock, and hopefully will carry on. Mr. Jerome Sikora wrote the original version of SPECTRA over two decades ago, and continues to direct its development. Many people have contributed to the current version of SPECTRA, most notably Mr. Jack Birmingham, Mr. John Andrews, and Mr. Alfred Dinsenbacher. More recent contributors are Mr. Jeffrey Beach, Mr. Thomas Brady, Mr. John Dalzell, Mr. William Hay, Dr. David Kihl, and Mr. Richard Lewis. Finally, the support of Mr. Allen Engle (formerly of NAVSEA 05, now at the Carderock Division), Mr. Jeff Hough, and Mr. Mike Sieve of NAVSEA 05 is greatly appreciated.

## Overview

SPECTRA computes vertical, lateral, and torsional moments applied to the hull girder of a monohull ship, as described by Sikora[i,ii]. Computations are based on the input parameters specified by the user. All inputs are located in the left frame of a file window, and output is displayed in the right frames, as shown in the Figure 1. SPECTRA uses a Multiple Document Interface (MDI), so many files can be open simultaneously – which makes comparison of inputs easy.

Inputs describe the general characteristics of the ship, and the type of environment in which the ship will operate. Outputs can be displayed as a graph, text, or both, which show the expected loads, based on the specified inputs.

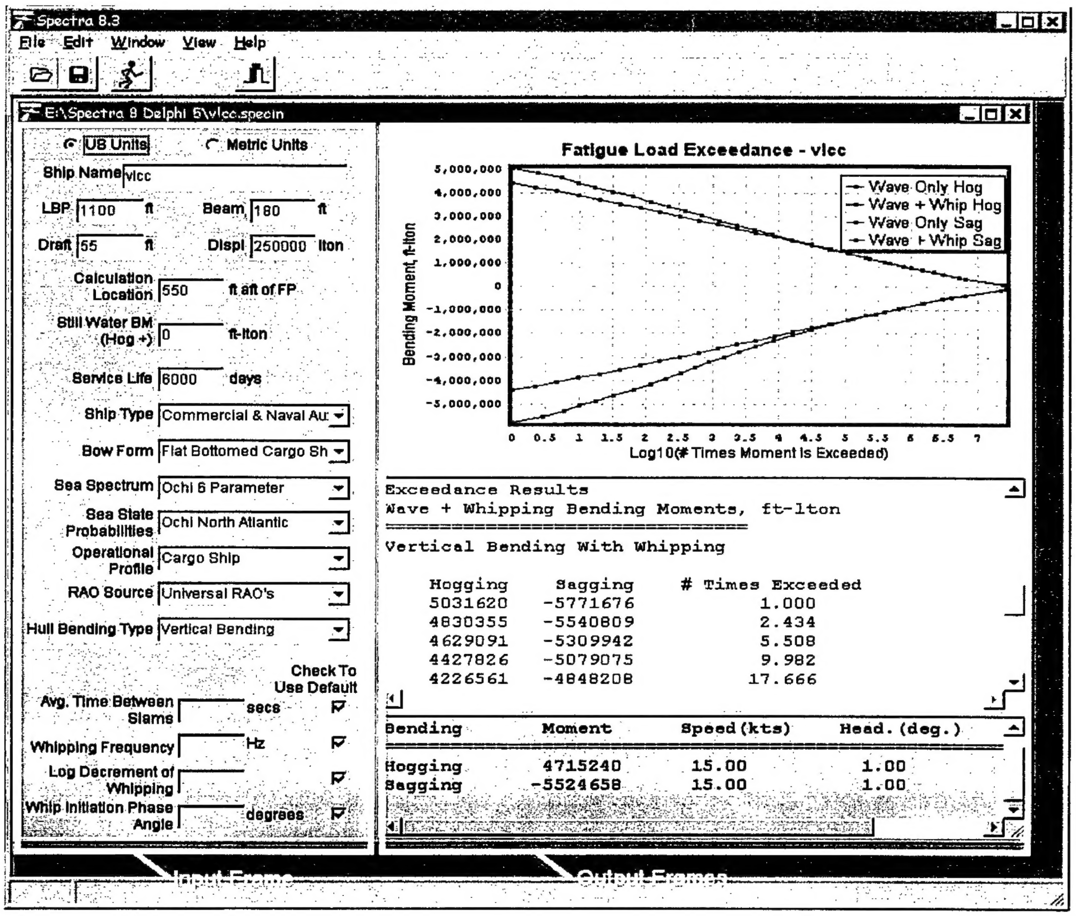



**Figure 1 - SPECTRA User Interface**

## Installation

SPECTRA will run on Windows 95, 98, or NT – based PCs. For installation, contact either:

Jerome Sikora
sikorajp@nswccd.navy.mil
301-227-1757

Robert Michaelson
michaelsonrw@nswccd.navy.mil
301-227-4200

## SPECTRA Input

### Ship Dimensions

Units: Select either U.S. or Metric.

LBP (ft. or m.): Length Between Perpendiculars – the length of the ship between the fore and aft perpendiculars. The fore perpendicular is the vertical line at the intersection of the fore side of the stem and the waterline. The aft perpendicular is the vertical line at the intersection of the summer load line and the aft side of the rudder post or sternpost, or the centerline of the rudder stock if there is no rudder post or stern post.

Beam (ft. or m.): The maximum breadth of the hull at or below the waterline.

Draft (ft. or m.): The depth of the ship below the waterline measured vertically to the lowest part of the hull proper (excluding sonar domes, appendages, etc.). For input into SPECTRA, this should be the mean draft of the hull (the average between the fore and aft drafts).

Displacement (lton. or mton.): The weight of the ship.

### Calculation Location

The calculation location is the ship section at which the bending moments will be determined when SPECTRA is run. This location is specified as a distance (ft. or m.) aft of the forward perpendicular.

### Still Water Bending Moment

The still water bending moment is the vertical bending moment of the ship in calm seas. The still water bending moment input for SPECTRA should coincide with the calculation location input. The still water bending moment is typically calculated

from programs such as Ship Hull Characteristics Program (SHCP).

**Service Life**

The service life is the expected number of days that the ship will be at sea. Historically, Navy ships have spent about one third of their life at sea. In the future, Navy ships are likely to spend about two thirds of their life at sea, due to fewer ships in the Fleet. So, for a 30-year ship life, about 7300 days will be spent at sea. If available, the ship's Operational Requirements Document should be consulted to determine service life and percent operability.

Commercial ships normally spend a higher percentage of their life at sea than Navy ships. This percentage can vary depending on the ship type and service. Typical service for commercial ships can be 300 or more days at sea per year.

With increasing sea time, the maximum lifetime bending moment does not increase much, but cycles at lower bending moments does. Thus fatigue cracks are more likely than hull girder failure if actual sea time exceeds the expected time at sea.

**Ship Type**

The ship type selection affects the magnitude of the wave-induced moments calculated within SPECTRA. Options of ship type listed within SPECTRA are:

<u>Commercial & Naval Auxiliaries –</u> typical commercial ships and Navy auxiliaries that operate at lower speeds and have a fuller hull form.

<u>Amphibious Assault –</u> ships such as LHA, LHD, LPD classes.

<u>Aircraft Carriers –</u> aircraft carriers such as CV and CVN classes.

<u>Frigates –</u> Navy frigates such as FFG and FF classes.

<u>DD-963 & CG-47 Class –</u> specifically for the DD-963 or CG-47 classes.

<u>DDG-51 Class –</u> specifically for the DDG-51 class.

<u>Other Destroyers & Cruisers –</u> destroyers or cruiser not of the DD-963, DDG-51, or CG-47 classes.

**Bow Form**

The bow form selection affects the whipping of the ship. Waves impacting on the bow of the ship can cause whipping. Thus, the shape of the bow, and the presence of

bulbs or sonar domes can affect the magnitude of whipping moments for vertical and lateral bending.

Options of bow form listed within SPECTRA are:

Fine Bow Frigate with V-Bow - ships such as FFG-7 class.

Fine Bow Frigate or Destroyer with Bow Dome - ships with fine bows and bulbs or domes at the bow.

Flared Bow Cruiser with Bow Dome - ships such as CG-47 class.

Flat Bottomed Cargo Ship - typical form of a tanker, oiler, or bulk carrier.

Amphibious Ship with Large Bow Flare - ships such as the LHD-1 and LHA-1 classes.

Aircraft Carrier with Large Bow Flare - aircraft carriers.

**Sea Spectrum**

The sea spectrum is a mathematical description of the seaway in which the ship will operate. A sea spectrum characterizes the height and length of the waves in the frequency domain. Options of sea spectrum listed within SPECTRA are:

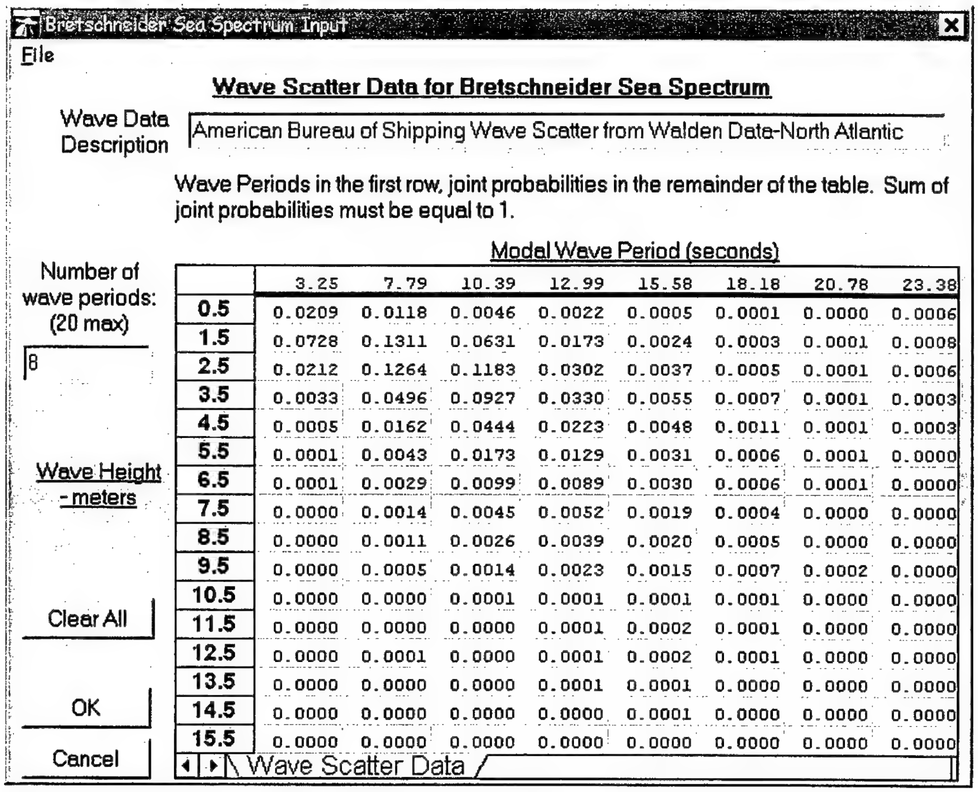
Pierson-Moskowitz – The Pierson-Moskowitz spectrum represents a "fully-developed" sea, meaning that fetch and duration are large, and there is no contamination from additional swells in the area. This sea spectrum is probably not appropriate for design use. It may be appropriate for extreme storm conditions.

Ochi 6 Parameter – The six parameters of the Ochi formulation generate a family of eleven spectral shapes for a given wave height. These shapes depict rising and fully developed seas as well as double-peaked spectra that occur when fresh, high-frequency seas occur in the presence of low-frequency swells. The Ochi spectrum was derived from North Atlantic data; it is recommended for design and for determining likely bending moments of ship structures in use in the North Atlantic.

North Atlantic 2 Parameter – The North Atlantic 2 Parameter spectrum is a form of the Bretschneider spectrum, with modal wave periods determined within the SPECTRA program. There are nine spectral shapes, each with an associated modal period for each wave height. The spectral shapes have the same area under the spectrum, but different peak energies. The North Atlantic 2 parameter spectrum has

the same limitations of the Bretshcneider spectrum.

Bretschneider – The Bretschneider spectrum allows for input of joint probabilities of wave height and modal period. The Bretschneider input form (Figure 2) appears, when the Bretschneider option is chosen from the sea spectrum drop-down list.


Bretschneider Sea Spectrum Input

File

**Wave Scatter Data for Bretschneider Sea Spectrum**

Wave Data Description: American Bureau of Shipping Wave Scatter from Walden Data-North Atlantic

Wave Periods in the first row, joint probabilities in the remainder of the table. Sum of joint probabilities must be equal to 1.

Number of wave periods: (20 max) 8

Wave Height - meters

Modal Wave Period (seconds)

| | 3.25 | 7.79 | 10.39 | 12.99 | 15.58 | 18.18 | 20.78 | 23.38 |
|---|---|---|---|---|---|---|---|---|
| 0.5 | 0.0209 | 0.0118 | 0.0046 | 0.0022 | 0.0005 | 0.0001 | 0.0000 | 0.0006 |
| 1.5 | 0.0728 | 0.1311 | 0.0631 | 0.0173 | 0.0024 | 0.0003 | 0.0001 | 0.0008 |
| 2.5 | 0.0212 | 0.1264 | 0.1183 | 0.0302 | 0.0037 | 0.0005 | 0.0001 | 0.0006 |
| 3.5 | 0.0033 | 0.0496 | 0.0927 | 0.0330 | 0.0055 | 0.0007 | 0.0001 | 0.0003 |
| 4.5 | 0.0005 | 0.0162 | 0.0444 | 0.0223 | 0.0048 | 0.0011 | 0.0001 | 0.0003 |
| 5.5 | 0.0001 | 0.0043 | 0.0173 | 0.0129 | 0.0031 | 0.0006 | 0.0001 | 0.0000 |
| 6.5 | 0.0001 | 0.0029 | 0.0099 | 0.0089 | 0.0030 | 0.0006 | 0.0001 | 0.0000 |
| 7.5 | 0.0000 | 0.0014 | 0.0045 | 0.0052 | 0.0019 | 0.0004 | 0.0000 | 0.0000 |
| 8.5 | 0.0000 | 0.0011 | 0.0026 | 0.0039 | 0.0020 | 0.0005 | 0.0000 | 0.0000 |
| 9.5 | 0.0000 | 0.0005 | 0.0014 | 0.0023 | 0.0015 | 0.0007 | 0.0002 | 0.0000 |
| 10.5 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | 0.0000 |
| 11.5 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0002 | 0.0001 | 0.0000 | 0.0000 |
| 12.5 | 0.0000 | 0.0001 | 0.0000 | 0.0001 | 0.0002 | 0.0001 | 0.0000 | 0.0000 |
| 13.5 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 14.5 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 15.5 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Clear All

OK

Cancel

Wave Scatter Data

Figure 2 - Bretschneider Input Form

Some details of the Bretschneider input form:

- Number of Wave Periods - The number of wave periods must be defined before the modal periods can be input.
- Modal Period - The modal period is the most likely wave period for a given wave height. Modal wave periods should be entered in the top row.
- Joint Probabilities - The joint probabilities represent the probability of a wave height and modal period occurring simultaneously. Ideally, the sum of all the probabilities should be one. However, SPECTRA does not explicitly check this. Joint probabilities of wave height and modal period should be entered in the body of the table.
- File Open and Save - Bretschneider files can be saved and re-opened for future

use. The "File" drop-down menu has file open and save choices.

The Bretschneider sea spectrum can be useful if the joint wave height and modal period probabilities are known for the operating area. However, it is limited in its ability to model seas in which high frequency waves (such as recently generated wind waves) occur in conjunction with long swells from a distant disturbance, which happens frequently.

**Sea State Probabilities**

Sea state probabilities represent the likelihood of the occurrence of certain wave heights. Within SPECTRA, wave heights are divided into 16 bands at 1-meter intervals. Thus the wave height bands in meters are, 0-1, 1-2, 2-3,...,15-16. Each wave height band is assigned a probability of occurrence, with the sum of the 16 probabilities being equal to 1. Ship operational requirements will dictate this choice, and should be consulted if available. SPECTRA has the following options for choosing sea state probabilities:

<u>Ochi North Atlantic -</u> Probabilities were obtained from wave buoy data at Station-I in the North Atlantic in the Greenland-Iceland gap. This is a severe set, with high probabilities for large waves.

<u>General Atlantic -</u> Probabilities are a combination of the Ochi North Atlantic with data from the Caribbean, Mediterranean, and Atlantic between the U.S. east coast, and Spain.

<u>General Pacific -</u> Probabilities assume equal amounts of time off the U.S. west coast, Hawaiian Islands, south of the Aleutian Islands, and around Japan.

<u>NATO North Atlantic -</u> Probabilities based on expected convoy routes between U.S. and Europe.

<u>Data File -</u> The user can recall a data file where previously saved wave height probabilities are stored.

<u>User Input -</u> The user can interactively input wave height probabilities, and save them to a file if desired.

Sea state probability files are simple text files that can be created or modified in an ASCII text editor. Below is a sample of a sea state probability file.

```
Spectra 8.0 Sea State Probabilities
 0.087
 0.192
 0.220
 0.157
 0.124
 0.080
 0.052
 0.039
 0.025
 0.013
 0.007
 0.004
 0.000
 0.000
 0.000
 0.000
```

Each wave height band is assigned a probability. The wave height probabilities are assigned sequentially within the program. So, for the above file:

0.087 is the probability of waves 0-1 meter high occurring,

0.192 for waves 1-2 meters,

0.220 for waves 2-3 meters, and so on.

If desired, you can input your own sea state probabilities. The input form (Figure 3) will pop-up if "User Input" is chosen in the Sea State Probabilities list box. Fill in the probability associated with each wave height, so that all of the probabilities sum to one. Once you have input the probabilities, you can save them to a sea state probability file for reuse.

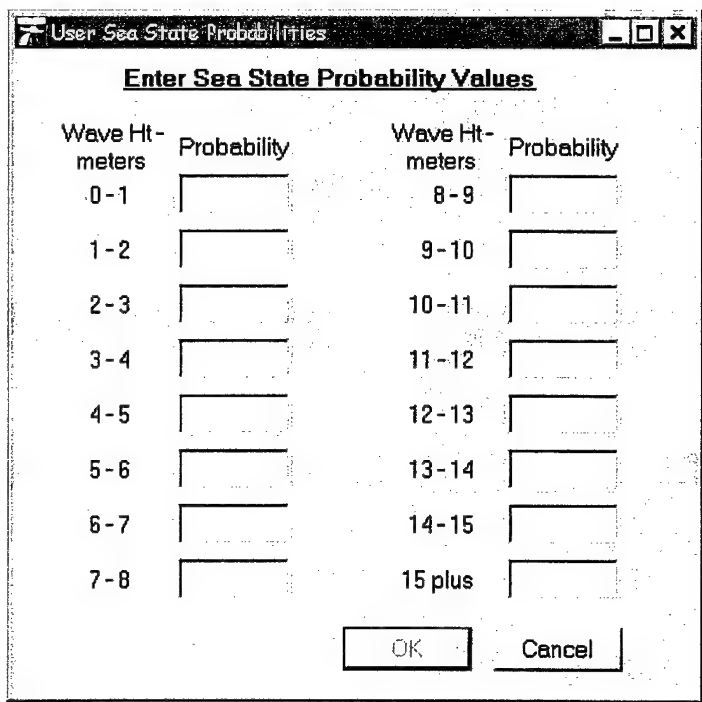



Figure 3 – Sea State Probability User Input Form

The built-in sea state probability options within the SPECTRA program should offer enough flexibility to model typical operating areas. The “User Input” and “Data File” choices give the

option for the user to add custom sea state probabilities if necessary.

**Operational Profile**

SPECTRA requires information on how a ship operates, given specific sea conditions. This information is provided in the operational profile. The ship's operation is divided into cells of ship speed, ship heading relative to wave direction, and wave height. Each cell is assigned a probability, which represents the fraction of the ship's life that will be spent in that operational cell. SPECTRA includes a number of built-in operational profiles. The user can also recall an operational profile data file of his/her choice if desired.

The choices within SPECTRA are listed below:

Combatant, Cargo Ship, Aircraft Carrier - Based on dialogue with ship operators on how the operators felt their ships operate in certain wave conditions. Headings relative to the waves are at 45-degree intervals (i.e., head, bow, beam, quartering, and following seas).

30-60 headings, 5-15-25 speeds - Modified combatant profile to include headings relative to the wave direction of 30 and 60 degrees. Lateral bending and torsion are most severe at a wave direction of 60 degrees. If calculating lateral bending or torsion of a combatant, this is the recommended operational profile.

Integrated Profiles for Combatant, Amphibious or Fast Cargo, Carrier, Auxiliary or Slow Cargo - These operational profiles are based on the operational profiles compiled by Michaelson with some "engineering judgement." The lower sea states assume random distribution of ship heading relative to the waves. The higher sea states use some interpretation, since there are very little data in higher sea states to form definitive conclusions. The integrated profiles adhere to the probabilities of the speed ranges from the Michaelson report.

Michaelson Profiles for Combatant, Amphibious or Fast Cargo, Carrier, Auxiliary or Slow Cargo - Michaelson[iii] compiled over 90,000 shipboard weather observations taken by ship personnel on a variety of U.S. Navy ships. These observations were processed into operational profiles, with fairly strict adherence to the observed data.

Data File - The user can select an operational profile for further customization. Operational profile files are simple text files that can be created or modified using an

ASCII text editor. Below is a sample operational profile file.

```
Spectra Operational Profile Data
'Auxiliaries and Commercial Ships
'number of speeds
2
'number of headings
5
'number of wave heights
3
'mean speeds - knots
5, 15
'mean headings - degrees off bow - 0 is head seas
0, 45, 90, 135, 180
'wave ht band definitions -
'wave hts defined in meters, up to 16 meters high max
'in 1 meter intervals (integers)
'band 1 -
1,5
'band 2 -
6,10
'band 3 -
11,16
'operational probabilities
'speed, heading, prob per wave height-
'given that the ship is operating in the given wave height,
'what is the probability of operating at the specified
'speed and heading
'spd hdg wvht1 wvht2 wvht3
 5,   0, 0.0100, 0.1250, 0.1750
 5,  45, 0.0200, 0.1250, 0.1750
 5,  90, 0.0200, 0.0625, 0.0875
 5, 135, 0.0200, 0.1250, 0.1750
 5, 180, 0.0100, 0.0625, 0.0875
15,   0, 0.1150, 0.1250, 0.0750
15,  45, 0.2300, 0.1250, 0.0750
15,  90, 0.2300, 0.0625, 0.0375
15, 135, 0.2300, 0.1250, 0.0750
15, 180, 0.1150, 0.0625, 0.0375
```

In the above file, lines that begin with an apostrophe (') are comments that will be disregarded by SPECTRA. The order of data in the file is important, and should be adhered to as the comments in the listing above describe.

The operational profile is probably the most ambiguous entry in SPECTRA. The operational profiles from Michaelson represent the most thorough attempt at determining this piece in the puzzle. However, the source of the data (shipboard weather observations) is by its nature open to human interpretation, and thus some judgement and possible modification of this data may be warranted. The "integrated" operational profile options represent a "best guess" interpretation of the Michaelson profiles. Without further study, the manner in which ships actually operate in various sea conditions will remain open to scrutiny.

**Response Amplitude Operators (RAOs)**

Response amplitude operators are transfer functions dependent upon the ship and operating conditions. The seaway provides input into the ship. Output from the system is the ship loads. RAOs mathematically represent the means by which the input (seaway) produces the output (bending moments).

Two choices for RAO source are listed - Universal RAOs, or Data File. Currently, SPECTRA only allows the use of Universal RAOs. The Universal RAOs are generated from algorithms that are based on data from model tests and full-scale trials.

The data file option is still under construction.

**Bending Type**

Ships can be bent in the vertical (hog and sag) and lateral planes of the hull girder.

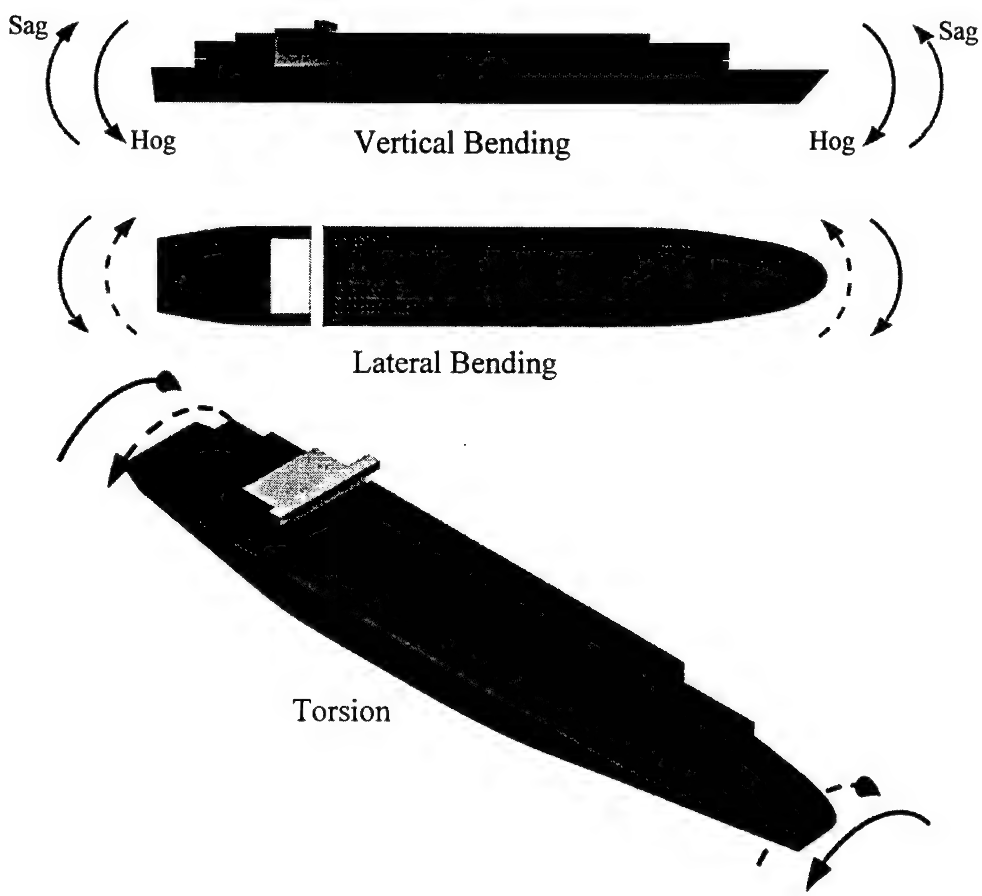



Figure 4 – Bending Moment Types

Also, the ship can be twisted about its longitudinal axis (torsion). SPECTRA has choices for determining vertical, lateral and torsional bending moments on the ship hull girder. Figure 4 shows the direction of the bending moment types.

## Whipping

Hull girder whipping is a vibration of the overall hull girder due to waves slamming on the bow of the ship. SPECTRA can calculate the whipping contribution to ship loads for vertical and lateral bending. Torsional whipping has not been found to be significant and thus is not included in SPECTRA.

Bottom Slamming: One typical slam event occurs from the sea impacting on the bottom of the ship at the bow, after the bow has emerged from the water during severe pitching. Ships with a flat bottom far forward tend to have more severe bottom slamming compared to ships with a V-shaped bow.

Bow Flare Slamming: Another slam event occurs from waves hitting the flared portion of the bow above the waterline as the bow pitches down into the waves. Ships with large bow flare will have more severe bow-flare slamming than ships with a fine bow above the waterline. The presence of a bow bulb or sonar dome at the bow can also affect the magnitude of whipping bending moments. The Bow Form input has several options that characterize the bow shape.

SPECTRA allows for manual input of several items for control of the whipping parameters, which are listed below.

### Average Time Between Slams

The average time between slams is the amount of time between slam events, provided that the ship is operating in conditions where slamming can occur.

SPECTRA will compute an average time in seconds between slam events unless one is input here. Slam rates can vary from about 20 to 40 slams per hour, depending on the ship and operating conditions.

### Whipping Frequency

After a slamming event, the hull girder will vibrate at its natural frequency.

SPECTRA will estimate the hull girder natural frequency if the user does not provide one.

Vertical Bending: SPECTRA uses a simple equation based on length:

$f_v = 302 / L^{0.884}$ = vertical bending natural frequency (hertz).

A more sophisticated equation based on beam theory for vertical bending is:

$f_v = 2.7 \, (EIg / (\Delta L^3))^{0.5}$ = vertical bending natural frequency (hertz).

E = modulus of elasticity of the material (long tons per $in^2$)

I = vertical moment of inertia of the hull girder ($in^2 ft^2$)

g = acceleration due to gravity = 32.2 $ft/sec^2$

$\Delta$ = displacement (long tons)

In the preliminary design stages, the designer does not usually know the moment of inertia, though. If "I" is known, then the user can input the calculated $f_v$.

Lateral Bending: As with vertical bending, SPECTRA uses a simple equation based on length:

$f_L = 400 / L^{0.884}$ = lateral bending natural frequency (hertz).

A more sophisticated equation based on beam theory for lateral bending is:

$f_L = C_L \, (EI_L g / (\Delta L^3))^{0.5}$ = vertical bending natural frequency (hertz).

$C_L$ = lateral frequency coefficient, taken as 2.55 [i]

E = modulus of elasticity of the material (long tons per $in^2$)

$I_L$ = lateral moment of inertia of the hull girder ($in^2 ft^2$)

g = acceleration due to gravity = 32.2 $ft/sec^2$

$\Delta$ = displacement (long tons)

## Log Decrement of Whipping

The log decrement of whipping quantifies the decrease of the hull girder whipping vibration with time, due to damping (mainly hydrodynamic).

SPECTRA computes the log decrement as 52 / L (L = length of the ship in feet) based on sea trial data, unless specified as input.

## Whipping Phase Angle

The whipping phase angle defines the point along the time history of bending moment at which slam-induced whipping begins.

Vertical Bending: The reference point for the whipping initiation phase angle is taken

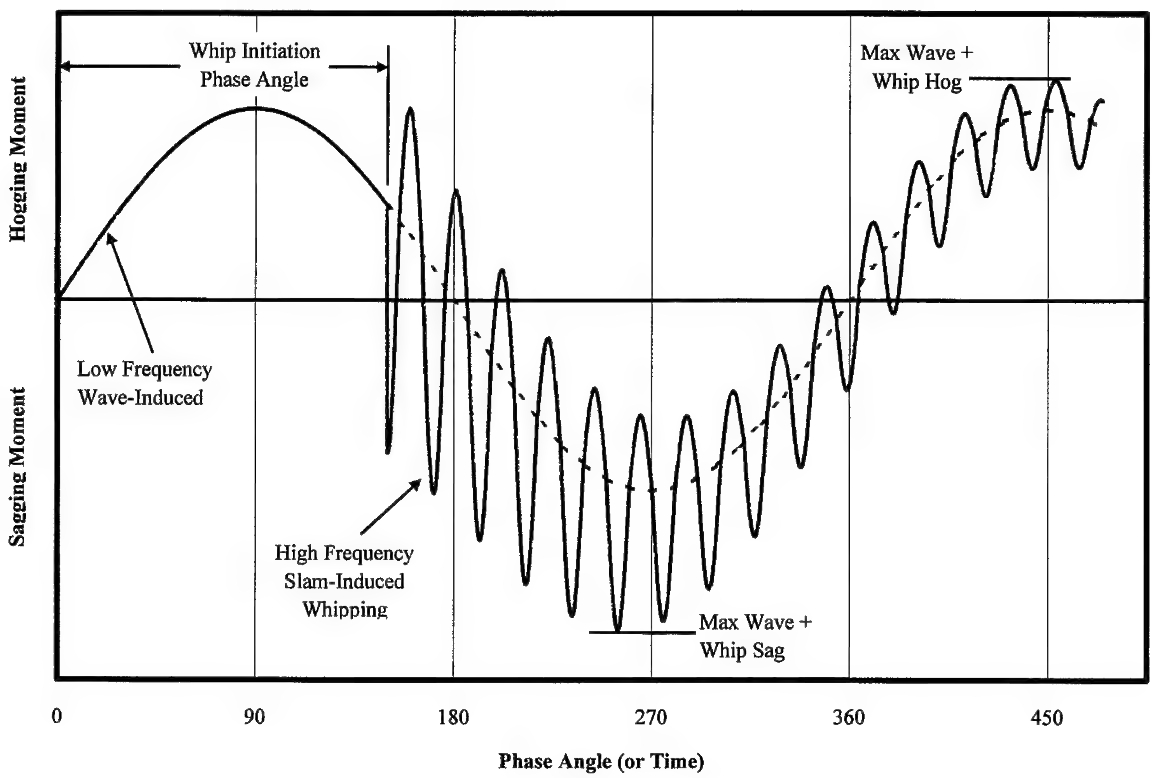



Figure 5 – History of Vertical Bending with Whipping

as the most recent zero up-crossing of the bending moment. Thus, in Figure 5, the whipping initiation phase angle is approximately 150 degrees.

Ship trials and model test data indicate that for hull bottom slamming, the whipping initiates at about 150 degrees. For bow flare slamming, a phase angle of 210 degrees may be appropriate. The default angle in SPECTRA is 150 degrees. Algorithms within SPECTRA are configured for vertical whipping initiation angles between 90 and 270 degrees. **If you input your own whip initiation phase angle, it should be between 90 and 270 degrees for vertical bending.**

Lateral Bending: The reference point for the whipping initiation phase angle is the most recent zero crossing of the bending moment. In Figure 6, the whipping initiation phase angle is roughly 70 degrees. There is little or no difference with the bending moment direction port to starboard as with vertical bending (hog vs. sag).

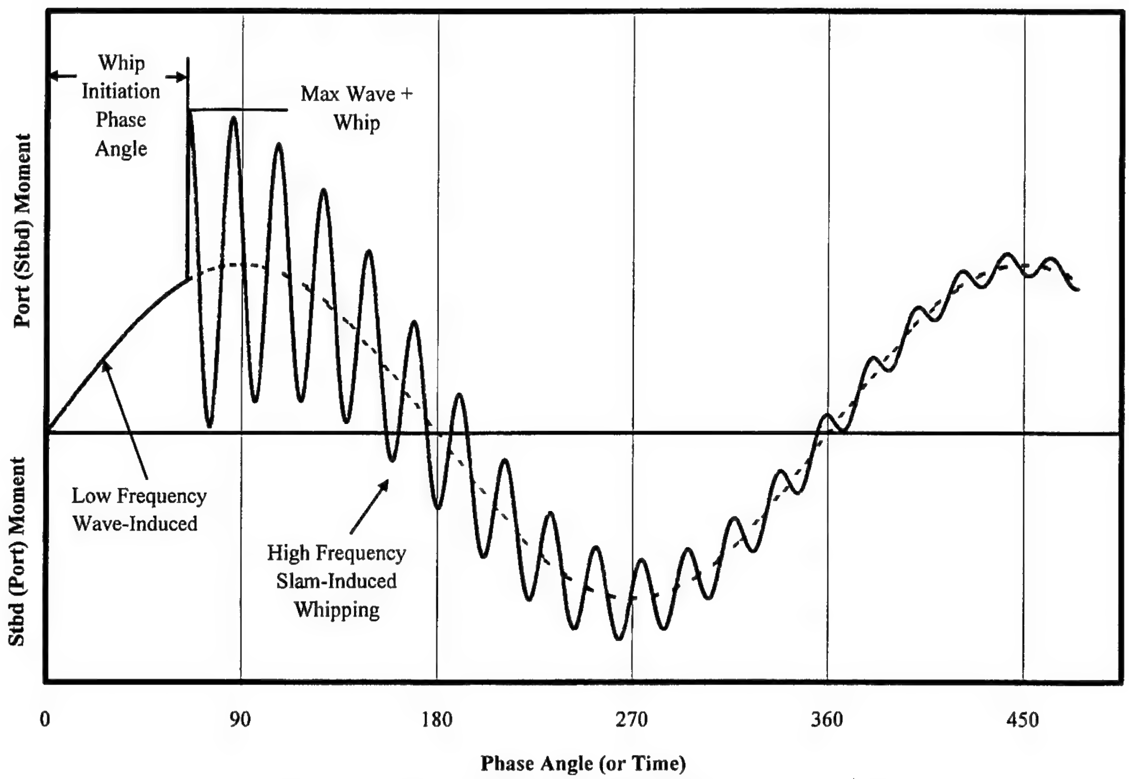



Figure 6 – History of Lateral Bending with Whipping

Ship trials and model test data show whipping initiation usually occurs just before the peak in a lateral bending moment cycle, with the default angle in SPECTRA being 68 degrees. **If you input your own whip initiation phase angle, it should be between 0 and 90 degrees for lateral bending.**

## Running Input

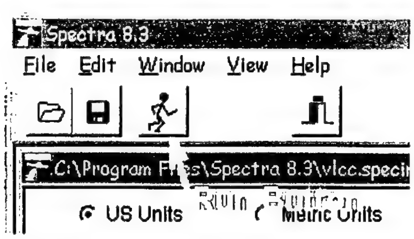



Figure 7 – Run Toolbar Buton

To perform calculations, the input data must be processed. Clicking the "running man" toolbar button at the top of the main window (Figure 7) generates output. If a change is made to the input, the output frames will be cleared, ensuring that

displayed output corresponds to the input. The input must also be complete for the run button to be activated.

## SPECTRA Output

### Output Overview

SPECTRA computes lifetime exceedance, histogram, and reliability information of hull girder bending moments. Exceedance and histogram results can be displayed in both graphical and text formats. The type of output to be displayed is designated from the View menu (Figure 8).

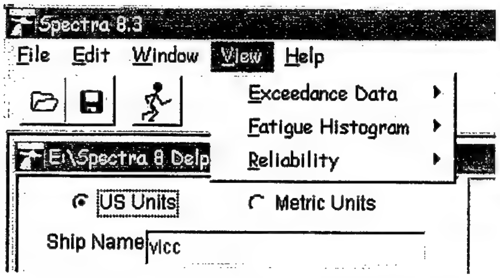



Figure 8 – View Menu for Output Selection

Figure 9 shows the typical output frames for vertical bending showing graphical and text

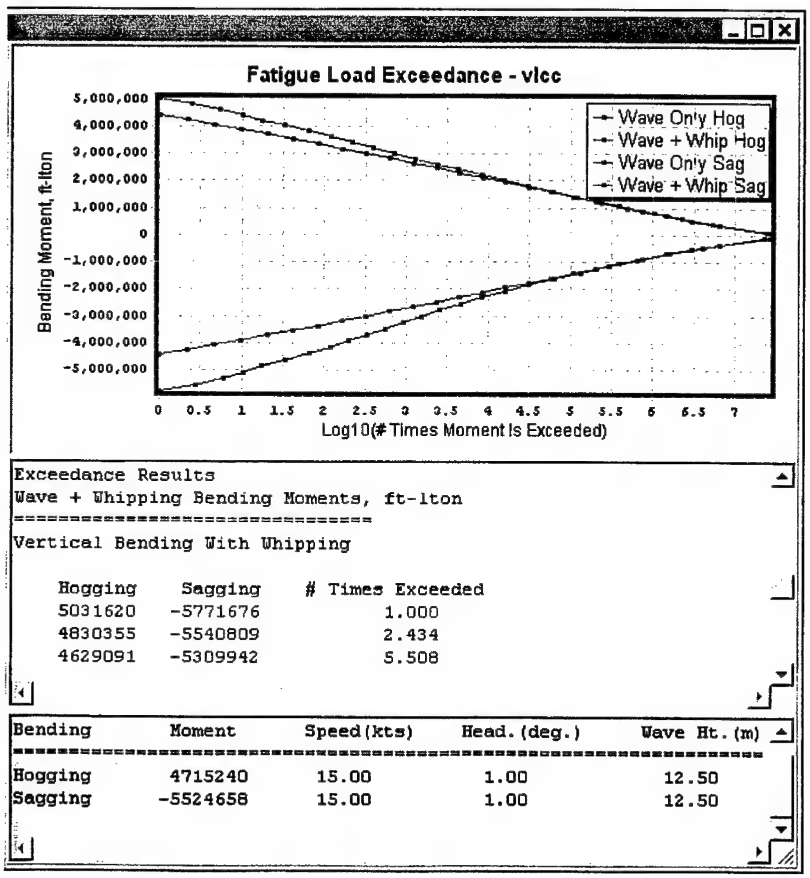



Figure 9 – SPECTRA Output

output. The bottom output frame always shows the operational cell in which the most severe bending moment occurs.

## Exceedance Output

Exceedance output can be displayed graphically, as text, or both. Display of exceedance output is designated in the View menu of the main SPECTRA window (Figure 10). Exceedance output gives the number of times in the life of the ship that a bending moment is equaled or exceeded. For vertical and lateral bending, wave- induced and wave plus whipping moments are displayed.

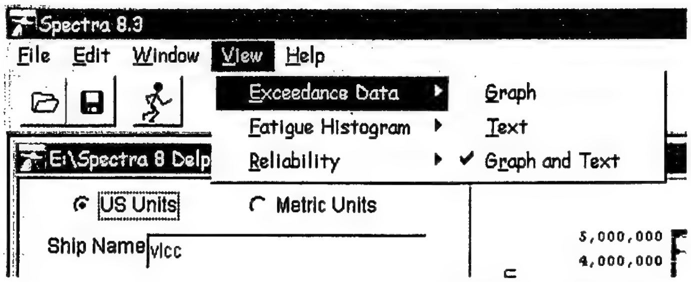
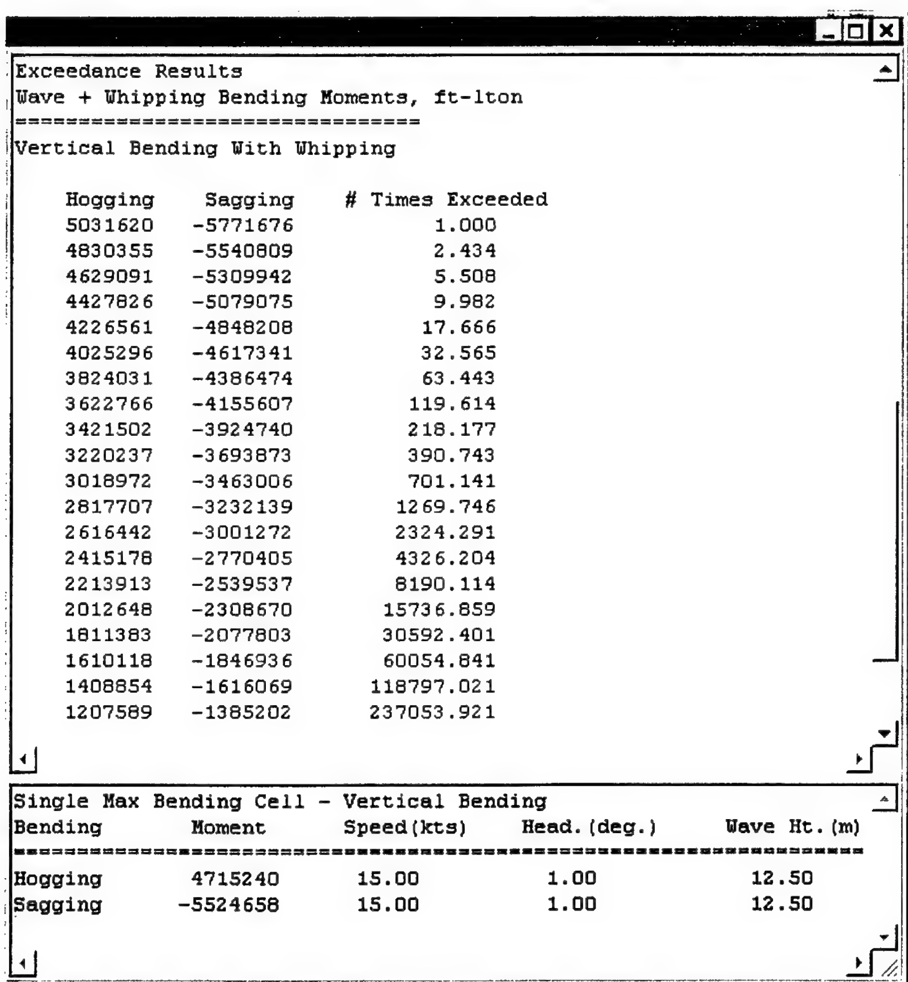



Figure 10 – Exceedance Output Menu Selection



Exceedance Results
Wave + Whipping Bending Moments, ft-lton

Vertical Bending With Whipping

| Hogging | Sagging | # Times Exceeded |
|---|---|---|
| 5031620 | -5771676 | 1.000 |
| 4830355 | -5540809 | 2.434 |
| 4629091 | -5309942 | 5.508 |
| 4427826 | -5079075 | 9.982 |
| 4226561 | -4848208 | 17.666 |
| 4025296 | -4617341 | 32.565 |
| 3824031 | -4386474 | 63.443 |
| 3622766 | -4155607 | 119.614 |
| 3421502 | -3924740 | 218.177 |
| 3220237 | -3693873 | 390.743 |
| 3018972 | -3463006 | 701.141 |
| 2817707 | -3232139 | 1269.746 |
| 2616442 | -3001272 | 2324.291 |
| 2415178 | -2770405 | 4326.204 |
| 2213913 | -2539537 | 8190.114 |
| 2012648 | -2308670 | 15736.859 |
| 1811383 | -2077803 | 30592.401 |
| 1610118 | -1846936 | 60054.841 |
| 1408854 | -1616069 | 118797.021 |
| 1207589 | -1385202 | 237053.921 |

Single Max Bending Cell - Vertical Bending

| Bending | Moment | Speed(kts) | Head.(deg.) | Wave Ht.(m) |
|---|---|---|---|---|
| Hogging | 4715240 | 15.00 | 1.00 | 12.50 |
| Sagging | -5524658 | 15.00 | 1.00 | 12.50 |

Figure 11 – Exceedance Output, Text Format

For torsion, only wave-induced moments are output. Text output for exceedance is shown in Figure 11.

### Fatigue Histogram Output

Fatigue histogram output can be displayed graphically, as text, or both. Display is designated in the View menu of the main SPECTRA window (Figure 12). Fatigue histogram output gives the number of times in the life of the ship that a range of moments will occur, with the mid-range moment listed in the output. This is useful in predicting the fatigue behavior

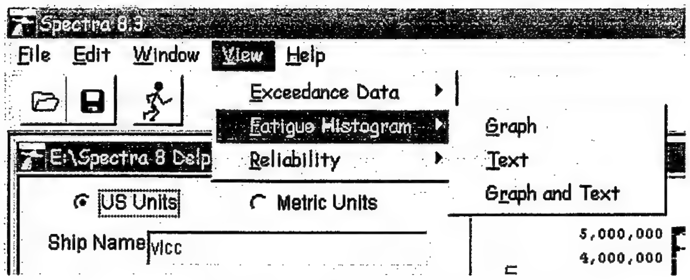



Figure 12 – Fatigue Histogram Output Menu Selection

Histogram Results
Wave + Whipping Bending Moments, ft-lton
================================
Vertical Bending With Whipping

| Hogging | Sagging | # Cycles at Moment |
|---|---|---|
| 4930988 | -5656243 | 1.434 |
| 4729723 | -5425376 | 3.074 |
| 4528458 | -5194508 | 4.474 |
| 4327193 | -4963641 | 7.684 |
| 4125928 | -4732774 | 14.899 |
| 3924664 | -4501907 | 30.878 |
| 3723399 | -4271040 | 56.171 |
| 3522134 | -4040173 | 98.563 |
| 3320869 | -3809306 | 172.566 |
| 3119604 | -3578439 | 310.398 |
| 2918340 | -3347572 | 568.605 |
| 2717075 | -3116705 | 1054.544 |
| 2515810 | -2885838 | 2001.913 |
| 2314545 | -2654971 | 3863.911 |
| 2113280 | -2424104 | 7546.745 |
| 1912016 | -2193237 | 14855.542 |
| 1710751 | -1962370 | 29462.440 |
| 1509486 | -1731503 | 58742.180 |
| 1308221 | -1500636 | 118256.900 |
| 1106956 | -1269769 | 244742.968 |
| 905692 | -1038902 | 532274.944 |

Single Max Bending Cell - Vertical Bending

| Bending | Moment | Speed(kts) | Head.(deg.) | Wave Ht.(m) |
|---|---|---|---|---|
| Hogging | 4715240 | 15.00 | 1.00 | 12.50 |
| Sagging | -5524658 | 15.00 | 1.00 | 12.50 |

Figure 13 – Fatigue Histogram Output, Text Format

of the ship's hull girder using cumulative damage theory. For vertical and lateral bending, wave induced, and wave plus whipping moments are displayed. For torsion, only wave-induced moments are output. Text output for histogram data is shown in Figure 13.

## Reliability Output

Reliability output can only be displayed as text. Display is designated in the View menu of the main SPECTRA window (Figure 14). Reliability output tabulates the probability that a given bending moment will **not** be exceeded. In addition, SPECTRA performs a Weibull

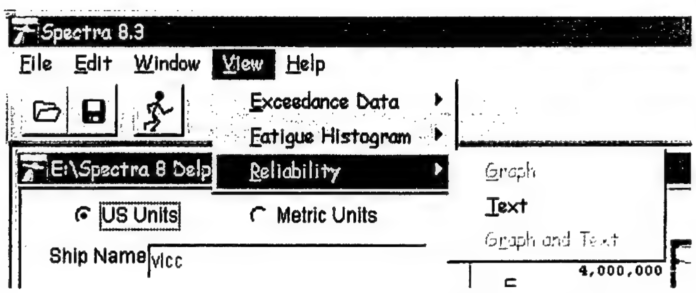



Figure 14 – Reliability Output Menu Selection

```
Reliability Results

  Lat ft-lton      Rel.        Weibull Fit
========================================
    2921314     0.367847       2917155
    3008953     0.719623       3007128
    3096592     0.901167       3100160
    3184232     0.968892       3189993
    3271871     0.990838       3276080
    3359511     0.997435       3359181
    3447150     0.999314       3440135
    3534790     0.999825       3519604
    3622429     0.999957       3598074
    3710068     0.999990       3675899
    3797708     0.999998       3753338

  Weibull Slope     =         1.395
  Truncation Value  =       2833674
  Scale             =        145999
  Mean X            =        133143
  Variance X        =    9355954470

Total wave encounters of all cells =      59857113

Single Max Bending Cell - Lateral Bending
Bending          Moment       Speed(kts)     Head.(deg.)      Wave Ht.(m)
=========================================================================
Lateral         2810501        15.00           45.00            11.50
```

Figure 15 – Reliability Output

fit for the tabulated moments. The moment for a given probability, R, is given by:

$$M = (\text{Truncation Value}) + \text{Scale}(-\ln(1 - R))^{1\,/\,(\text{Weibull Slope})}$$

Figure 15 is a sample of reliability output for lateral bending as computed by SPECTRA.

## Copying and Printing Output

Both graphical and text output can be copied to the clipboard or printed to your system printer. Right-clicking the mouse on the graph or text output frames will pop-up a menu with options for copying or printing the graph or selected text output. When copying or printing the graph, best results are obtained if the graph is as large as possible on your screen

---

[i] Sikora, J., "Cumulative Lifetime Loadings for Naval Ships", 1998 International Mechanical Engineering Congress & Exposition, Anaheim CA, USA, Nov. 1998.

[ii] Sikora, J., "Design Methodology for Seaway Loads", NSWCCD Report 65-TR-1999/16, September 1999.

[iii] Michaelson, R. "Ship Operational Profiles Compiled from Shipboard Weather Observations of 40 U.S. Navy Ships", NSWCCD Report TR-65-96/07, June 1996.

## Appendix A – Sample Input and Output

SPECTRA automatically installs three sample files during the program setup, "vlcc.specin", "cargo.specin", and "vlcc-metric.specin". It is suggested that the user run the program using these files to ensure the program is operating correctly and to gain familiarity with its use. Input and output listings are provided below.

**vlcc.specin:**

Input:

```
US units
Ship Name= vlcc
LBP= 1100
Beam= 180
Draft= 55
Displacement= 250000
Calculation Location= 550
Still Water Bend.Moment= 0
Ship Type= Commercial & Naval Auxiliaries
Bow Shape= Flat Bottomed Cargo Ship
Service Life= 6000
RAO Source= Universal RAO's
Hull Bending= Vertical Bending
Sea Spectrum= Ochi 6 Parameter
Sea State Probabilities= Ochi North Atlantic
Operational Profile= Cargo Ship
Avg Time Between Slams= Default
Whipping Frequency= Default
Whipping Log Decrement= Default
Whipping Initiation Phase Angle= Default
```

Output:

```
Exceedance Results
Wave Induced Moments, ft-lton
================================
Vertical Bending
    Hogging    Sagging     # Times Exceeded
    4419337   -4419337            1.000
    4242563   -4242563            2.179
    4065790   -4065790            4.666
    3889016   -3889016            9.822
    3712243   -3712243           20.340
    3535469   -3535469           41.473
    3358696   -3358696           83.358
    3181922   -3181922          165.417
    3005149   -3005149          324.683
    2828375   -2828375          631.649
    2651602   -2651602         1220.489
    2474829   -2474829         2346.617
    2298055   -2298055         4495.581
    2121282   -2121282         8587.119
    1944508   -1944508        16353.539
    1767735   -1767735        31037.539
    1590961   -1590961        58686.102
    1414188   -1414188       110604.347
    1237414   -1237414       208224.723
    1060641   -1060641       393508.075
     883867    -883867       753291.096
     707094    -707094      1479858.640
```

| | | |
|---|---|---|
| 530320 | -530320 | 3030887.368 |
| 353547 | -353547 | 6622623.963 |
| 88387 | -88387 | 26759677.078 |

```
Exceedance Results
Wave + Whipping Bending Moments, ft-lton
================================
Vertical Bending With Whipping
```

| Hogging | Sagging | # Times Exceeded |
|---|---|---|
| 5032133 | -5772263 | 1.000 |
| 4830848 | -5541373 | 2.434 |
| 4629563 | -5310482 | 5.507 |
| 4428277 | -5079592 | 9.980 |
| 4226992 | -4848701 | 17.661 |
| 4025707 | -4617811 | 32.555 |
| 3824421 | -4386920 | 63.419 |
| 3623136 | -4156030 | 119.574 |
| 3421851 | -3925139 | 218.096 |
| 3220565 | -3694248 | 390.595 |
| 3019280 | -3463358 | 700.869 |
| 2817995 | -3232467 | 1269.229 |
| 2616709 | -3001577 | 2323.301 |
| 2415424 | -2770686 | 4324.266 |
| 2214139 | -2539796 | 8186.276 |
| 2012853 | -2308905 | 15729.281 |
| 1811568 | -2078015 | 30577.537 |
| 1610283 | -1847124 | 60026.145 |
| 1408997 | -1616234 | 118742.815 |
| 1207712 | -1385343 | 236953.022 |
| 1006427 | -1154453 | 481606.894 |
| 805141 | -923562 | 1013709.998 |
| 603856 | -692672 | 2235375.664 |
| 402571 | -461781 | 5285415.875 |
| 100643 | -115445 | 24942602.490 |

## cargo.specin:

<u>Input:</u>

```
Ship Name= cargo
LBP= 800
Beam= 105
Draft= 44
Displacement= 80000
Calculation Location= 400
Still Water Bend.Moment= 0
Ship Type= Commercial & Naval Auxiliaries
Bow Shape= Flat Bottomed Cargo Ship
Service Life= 6000
RAO Source= Universal RAO's
Hull Bending= Vertical Bending
Sea Spectrum= Ochi 6 Parameter
Sea State Probabilities= General Atlantic
Operational Profile= Cargo Ship
Avg Time Between Slams= Default
Whipping Frequency= Default
Whipping Log Decrement= Default
Whipping Initiation Phase Angle= Default
```

## Output:

Exceedance Results
Wave Induced Moments, ft-lton
================================
Vertical Bending

| Hogging | Sagging | # Times Exceeded |
|---|---|---|
| 1137274 | -1137274 | 1.000 |
| 1091783 | -1091783 | 2.135 |
| 1046292 | -1046292 | 4.495 |
| 1000801 | -1000801 | 9.340 |
| 955310 | -955310 | 19.141 |
| 909819 | -909819 | 38.695 |
| 864328 | -864328 | 77.168 |
| 818837 | -818837 | 151.857 |
| 773346 | -773346 | 295.040 |
| 727855 | -727855 | 566.411 |
| 682364 | -682364 | 1075.677 |
| 636873 | -636873 | 2023.747 |
| 591382 | -591382 | 3778.095 |
| 545891 | -545891 | 7011.102 |
| 500400 | -500400 | 12954.630 |
| 454909 | -454909 | 23870.155 |
| 409418 | -409418 | 43925.373 |
| 363928 | -363928 | 80865.501 |
| 318437 | -318437 | 149313.972 |
| 272946 | -272946 | 277588.666 |
| 227455 | -227455 | 522939.843 |
| 181964 | -181964 | 1009476.163 |
| 136473 | -136473 | 2042119.795 |
| 90982 | -90982 | 4508417.432 |
| 22745 | -22745 | 21227087.381 |

Exceedance Results
Wave + Whipping Bending Moments, ft-lton
================================
Vertical Bending With Whipping

| Hogging | Sagging | # Times Exceeded |
|---|---|---|
| 1268719 | -1498751 | 1.000 |
| 1217970 | -1438801 | 2.494 |
| 1167221 | -1378851 | 5.935 |
| 1116473 | -1318901 | 11.448 |
| 1065724 | -1258951 | 21.766 |
| 1014975 | -1199001 | 41.769 |
| 964226 | -1139051 | 77.493 |
| 913478 | -1079101 | 139.096 |
| 862729 | -1019151 | 245.549 |
| 811980 | -959201 | 428.111 |
| 761231 | -899251 | 748.577 |
| 710483 | -839301 | 1315.223 |
| 659734 | -779351 | 2324.892 |
| 608985 | -719401 | 4158.758 |
| 558236 | -659451 | 7530.803 |
| 507488 | -599500 | 13796.008 |
| 456739 | -539550 | 25594.947 |
| 405990 | -479600 | 48176.430 |
| 355241 | -419650 | 92350.064 |
| 304493 | -359700 | 180827.914 |
| 253744 | -299750 | 361966.822 |
| 202995 | -239800 | 741808.744 |
| 152246 | -179850 | 1587292.335 |
| 101498 | -119900 | 3714980.088 |
| 25374 | -29975 | 19910768.082 |

**vlcc-metric.specin:**

Input:

```
Ship Name= vlcc-metric
LBP= 335.28
Beam= 54.86
Draft= 16.76
Displacement= 254083
Calculation Location= 167.64
Still Water Bend.Moment= 0
Ship Type= Commercial & Naval Auxiliaries
Bow Shape= Flat Bottomed Cargo Ship
Service Life= 6000
RAO Source= Universal RAO's
Hull Bending= Vertical Bending
Sea Spectrum= Ochi 6 Parameter
Sea State Probabilities= Ochi North Atlantic
Operational Profile= Cargo Ship
Avg Time Between Slams= Default
Whipping Frequency= Default
Whipping Log Decrement= Default
Whipping Initiation Phase Angle= Default
```

Output:

```
Exceedance Results
Wave Induced Moments, m-mton
================================
Vertical Bending
    Hogging     Sagging    # Times Exceeded
    1368533    -1368533          1.000
    1313792    -1313792          2.179
    1259051    -1259051          4.666
    1204309    -1204309          9.822
    1149568    -1149568         20.340
    1094827    -1094827         41.473
    1040085    -1040085         83.358
     985344     -985344        165.417
     930603     -930603        324.683
     875861     -875861        631.649
     821120     -821120       1220.489
     766379     -766379       2346.617
     711637     -711637       4495.581
     656896     -656896       8587.119
     602155     -602155      16353.539
     547413     -547413      31037.539
     492672     -492672      58686.102
     437931     -437931     110604.347
     383189     -383189     208224.723
     328448     -328448     393508.075
     273707     -273707     753291.096
     218965     -218965    1479858.640
     164224     -164224    3030887.368
     109483     -109483    6622623.963
      27371      -27371   26759677.078


Exceedance Results
Wave + Whipping Bending Moments, m-mton
================================
Vertical Bending With Whipping
```

| Hogging | Sagging | # Times Exceeded |
|---|---|---|
| 1558298 | -1787493 | 1.000 |
| 1495966 | -1715994 | 2.434 |
| 1433634 | -1644494 | 5.507 |
| 1371302 | -1572994 | 9.980 |
| 1308970 | -1501494 | 17.661 |
| 1246638 | -1429995 | 32.555 |
| 1184306 | -1358495 | 63.419 |
| 1121974 | -1286995 | 119.574 |
| 1059643 | -1215496 | 218.096 |
| 997311 | -1143996 | 390.595 |
| 934979 | -1072496 | 700.869 |
| 872647 | -1000996 | 1269.229 |
| 810315 | -929497 | 2323.301 |
| 747983 | -857997 | 4324.266 |
| 685651 | -786497 | 8186.276 |
| 623319 | -714997 | 15729.281 |
| 560987 | -643498 | 30577.537 |
| 498655 | -571998 | 60026.145 |
| 436323 | -500498 | 118742.815 |
| 373991 | -428998 | 236953.022 |
| 311660 | -357499 | 481606.894 |
| 249328 | -285999 | 1013709.998 |
| 186996 | -214499 | 2235375.664 |
| 124664 | -142999 | 5285415.875 |
| 31166 | -35750 | 24942602.490 |

## Appendix B – Sea Spectra

SPECTRA includes four built-in sea spectra. The formulations for these spectra are given below.

**Pierson-Moskowitz**

The Pierson-Moskowitz spectrum for fully developed seas can be used to generate one spectral shape for a given wave height by,

$$S(\omega) = 0.0081\frac{g^2}{\omega^5}\exp\left(-0.032\left(\frac{g}{H\omega^2}\right)\right)$$

where

$S(\omega)$ = spectral density function

$g$ = acceleration due to gravity

$\omega$ = non - dimenisonal wave frequency, rad/sec

$H$ = significant wave height

**Ochi 6 Parameter**

The Ochi 6 parameter spectrum is composed of 11 spectral shapes for a given wave height, with each spectral shape having its own probability of occurrence for a given wave height. The formulation is defined as:

$$S(\omega) = \frac{1}{4}\sum_{j=1}^{2}\frac{\left(\frac{4\lambda_j+1}{4}\omega_{mj}^4\right)^{\lambda_j}}{\Gamma(\lambda_j)} \bullet \frac{H_{sj}^2}{\omega^{4\lambda_j+1}} \bullet \exp\left(-\frac{4\lambda_j+1}{4}\left(\frac{\omega_{mj}}{\omega}\right)^4\right)$$

where

$S(\omega)$ = spectral density function

$\Gamma$ = gamma function

$\lambda$ = shape parameter

$H_s$ = wave height parameter

$\omega$ = non - dimensional wave frequency, rad/sec

$\omega_m$ = modal frequency parameter

j = 1 or 2 for low and high frequency components

The six parameters, $H_{s1}$, $H_{s2}$, $\omega_{m1}$, $\omega_{m2}$, $\lambda_1$, and $\lambda_2$ are listed in Table B1.

Table B1 – Six Ochi Parameters as Functions of Significant Wave Height

| Spectral Shape | Probability | $H_{s1}$ | $H_{s2}$ | $\omega_{m1}$ | $\omega_{m2}$ | $\lambda_1$ | $\lambda_2$ |
|---|---|---|---|---|---|---|---|
| 1 | 0.50 | $0.84\zeta$ | $0.54\zeta$ | $0.70e^{-0.046\zeta}$ | $1.15e^{-0.039\zeta}$ | 3.00 | $1.54e^{-0.062\zeta}$ |
| 2 | 0.05 | $0.95\zeta$ | $0.31\zeta$ | $0.70e^{-0.046\zeta}$ | $0.50e^{-0.046\zeta}$ | 1.35 | $2.48e^{-0.102\zeta}$ |
| 3 | 0.05 | $0.65\zeta$ | $0.76\zeta$ | $0.61e^{-0.039\zeta}$ | $0.94e^{-0.036\zeta}$ | 4.95 | $2.48e^{-0.102\zeta}$ |
| 4 | 0.05 | $0.84\zeta$ | $0.54\zeta$ | $0.93e^{-0.056\zeta}$ | $1.50e^{-0.046\zeta}$ | 3.00 | $2.77e^{-0.112\zeta}$ |
| 5 | 0.05 | $0.84\zeta$ | $0.54\zeta$ | $0.41e^{-0.016\zeta}$ | $0.88e^{-0.026\zeta}$ | 2.55 | $1.82e^{-0.089\zeta}$ |
| 6 | 0.05 | $0.90\zeta$ | $0.44\zeta$ | $0.81e^{-0.052\zeta}$ | $1.60e^{-0.033\zeta}$ | 1.80 | $2.95e^{-0.105\zeta}$ |
| 7 | 0.05 | $0.77\zeta$ | $0.64\zeta$ | $0.54e^{-0.039\zeta}$ | 0.61 | 4.50 | $1.95e^{-0.082\zeta}$ |
| 8 | 0.05 | $0.73\zeta$ | $0.68\zeta$ | $0.70e^{-0.046\zeta}$ | $0.99e^{-0.039\zeta}$ | 6.40 | $1.78e^{-0.069\zeta}$ |
| 9 | 0.05 | $0.92\zeta$ | $0.39\zeta$ | $0.70e^{-0.046\zeta}$ | $1.37e^{-0.039\zeta}$ | 0.70 | $1.78e^{-0.069\zeta}$ |
| 10 | 0.05 | $0.84\zeta$ | $0.54\zeta$ | $0.74e^{-0.052\zeta}$ | $1.30e^{-0.039\zeta}$ | 2.65 | $3.90e^{-0.085\zeta}$ |
| 11 | 0.05 | $0.84\zeta$ | $0.54\zeta$ | $0.62e^{-0.039\zeta}$ | $1.03e^{-0.030\zeta}$ | 2.60 | $0.53e^{-0.069\zeta}$ |

$\zeta$ = significant wave height.

## North Atlantic 2 Parameter

The North Atlantic 2 parameter spectrum is composed of nine spectral shapes for a given wave height. The formulation is:

$$S(\omega) = 0.3125\frac{\omega_m^4 H^2}{\omega^5}\exp\left(-1.25\left(\frac{\omega_m}{\omega}\right)^4\right)$$

where

$S(\omega)$ = spectral density function

$\omega_m$ = modal wave period

$\omega$ = wave frequency, rad/sec

$H$ = significant wave height

Thus this spectrum has two parameters, $\omega_m$ and $H$. For a given wave height, $H$, the modal period and spectral shape probability for this spectrum is shown in Table B2.

Table B2 – Modal Period and Spectral Shape Probability for North Atlantic 2 Parameter Sea Spectra

| Spectral Shape | Probability | $\omega_m$ (rad/sec) |
|---|---|---|
| 1 | 0.0500 | 0.048( 8.75 - ln(H) ) |
| 2 | 0.0500 | 0.054( 8.44 - ln(H) ) |
| 3 | 0.0875 | 0.061( 8.07 - ln(H) ) |
| 4 | 0.1875 | 0.069( 7.77 - ln(H) ) |
| 5 | 0.2500 | 0.079( 7.63 - ln(H) ) |
| 6 | 0.1875 | 0.099( 6.87 - ln(H) ) |
| 7 | 0.0875 | 0.111( 6.67 - ln(H) ) |
| 8 | 0.0500 | 0.119( 6.65 - ln(H) ) |
| 9 | 0.0500 | 0.134( 6.41 - ln(H) ) |

**Bretschnieder**

The basic form of the Bretschnieder spectrum is the same as the North Atlantic 2 parameter, except that use of the Bretschnieder spectrum, requires a tabulation of joint modal period and wave height probabilities. A sample of joint probabilities is given in Table B3.

Table B3 - Joint Wave Height and Modal Period Probabilities Sample

| Wave Height - meters | Modal wave period (seconds) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 3.25 | 7.79 | 10.39 | 12.99 | 15.58 | 18.18 | 20.78 | 23.38 |
| 0.5 | 0.02091 | 0.01179 | 0.00457 | 0.00224 | 0.00047 | 0.00006 | 0.00000 | 0.00060 |
| 1.5 | 0.07278 | 0.13108 | 0.06308 | 0.01726 | 0.00239 | 0.00033 | 0.00011 | 0.00077 |
| 2.5 | 0.02124 | 0.12641 | 0.11831 | 0.03024 | 0.00368 | 0.00047 | 0.00009 | 0.00056 |
| 3.5 | 0.00328 | 0.04960 | 0.09269 | 0.03299 | 0.00546 | 0.00068 | 0.00012 | 0.00027 |
| 4.5 | 0.00053 | 0.01619 | 0.04436 | 0.02228 | 0.00479 | 0.00114 | 0.00008 | 0.00029 |
| 5.5 | 0.00012 | 0.00434 | 0.01730 | 0.01289 | 0.00313 | 0.00056 | 0.00013 | 0.00004 |
| 6.5 | 0.00007 | 0.00290 | 0.00990 | 0.00886 | 0.00303 | 0.00059 | 0.00008 | 0.00003 |
| 7.5 | 0.00003 | 0.00139 | 0.00447 | 0.00522 | 0.00193 | 0.00038 | 0.00004 | 0.00004 |
| 8.5 | 0.00000 | 0.00109 | 0.00255 | 0.00392 | 0.00198 | 0.00050 | 0.00003 | 0.00002 |
| 9.5 | 0.00000 | 0.00054 | 0.00136 | 0.00226 | 0.00154 | 0.00068 | 0.00020 | 0.00004 |
| 10.5 | 0.00001 | 0.00001 | 0.00010 | 0.00011 | 0.00010 | 0.00005 | 0.00002 | 0.00000 |
| 11.5 | 0.00000 | 0.00000 | 0.00003 | 0.00008 | 0.00017 | 0.00006 | 0.00000 | 0.00000 |
| 12.5 | 0.00000 | 0.00005 | 0.00000 | 0.00014 | 0.00022 | 0.00006 | 0.00001 | 0.00000 |
| 13.5 | 0.00000 | 0.00002 | 0.00000 | 0.00007 | 0.00009 | 0.00003 | 0.00000 | 0.00001 |
| 14.5 | 0.00000 | 0.00000 | 0.00000 | 0.00002 | 0.00006 | 0.00002 | 0.00000 | 0.00001 |
| 15.5 | 0.00000 | 0.00002 | 0.00000 | 0.00001 | 0.00001 | 0.00002 | 0.00001 | 0.00001 |

SPECTRA will compute a sea spectral shape for each of the joint probabilities using the applicable modal periods and wave heights. Thus for Table B3, 128 spectral shapes would be computed using the same equation as for the North Atlantic 2 parameter spectra,

$$S(\omega) = 0.3125 \frac{\omega_m^4 H^2}{\omega^5} \exp\left(-1.25\left(\frac{\omega_m}{\omega}\right)^4\right),$$

with each spectral shape being assigned its associated probability of occurrence. For example, one of the 128 spectral shapes would be calculated with $\omega_m = 3.25$ and $H = 0.5$, with the probability of occurrence being 0.02091.

## Appendix C – Sea State Probabilities

SPECTRA includes four pre-defined sea state probability choices - Ochi North Atlantic, General Atlantic, General Pacific, and NATO North Atlantic (Table C1). The sea state probabilities represent the probability of occurrence of a given wave height.

Table C1 - Sea State Probabilities

| Significant Wave Height (meters) | Ochi North Atlantic | General Atlantic | General Pacific | NATO North Atlantic |
|---|---|---|---|---|
| < 1 | 0.050300 | 0.369200 | 0.225411 | 0.087000 |
| 1 - 2 | 0.266500 | 0.330300 | 0.384911 | 0.192000 |
| 2 - 3 | 0.260300 | 0.148000 | 0.230511 | 0.220000 |
| 3 - 4 | 0.175700 | 0.072300 | 0.094511 | 0.157000 |
| 4 - 5 | 0.101400 | 0.035500 | 0.030341 | 0.124000 |
| 5 - 6 | 0.058900 | 0.018100 | 0.017361 | 0.080000 |
| 6 - 7 | 0.034600 | 0.011000 | 0.006761 | 0.052000 |
| 7 - 8 | 0.020900 | 0.006600 | 0.003911 | 0.039000 |
| 8 - 9 | 0.012000 | 0.003600 | 0.003131 | 0.025000 |
| 9 - 10 | 0.007900 | 0.002470 | 0.001781 | 0.013000 |
| 10 - 11 | 0.005400 | 0.001380 | 0.000591 | 0.007000 |
| 11 - 12 | 0.002900 | 0.000740 | 0.000321 | 0.004000 |
| 12 - 13 | 0.001600 | 0.000400 | 0.000321 | 0.000000 |
| 13 - 14 | 0.000740 | 0.000190 | 0.000111 | 0.000000 |
| 14 - 15 | 0.000450 | 0.000120 | 0.000021 | 0.000000 |
| >15 | 0.000410 | 0.000100 | 0.000000 | 0.000000 |

# Appendix D – Operational Profiles

SPECTRA includes 12 operational profiles which describe a ship's operational characteristics with respect to speed, wave height, and heading relative to wave direction (0 degrees is head seas). These operational profiles are listed in the tables below.

Table D1 - Operational Profile: Combatant

| | | Significant Wave Height (meters) | | |
|---|---|---|---|---|
| Speed (kts) | Heading | 0 - 5 | 6 - 10 | > 10 |
| 5 | 0 | 0.01250 | 0.02500 | 0.00000 |
| 5 | 45 | 0.02500 | 0.37500 | 0.80800 |
| 5 | 80 | 0.02500 | 0.05000 | 0.00000 |
| 5 | 135 | 0.02500 | 0.05000 | 0.04200 |
| 5 | 180 | 0.01250 | 0.02500 | 0.00000 |
| 15 | 0 | 0.08750 | 0.02300 | 0.00000 |
| 15 | 45 | 0.17500 | 0.33750 | 0.14200 |
| 15 | 90 | 0.17500 | 0.00000 | 0.00000 |
| 15 | 135 | 0.17500 | 0.04450 | 0.00800 |
| 15 | 180 | 0.08750 | 0.02250 | 0.00000 |
| 25 | 0 | 0.02500 | 0.00250 | 0.00000 |
| 25 | 45 | 0.05000 | 0.03750 | 0.00000 |
| 25 | 90 | 0.05000 | 0.00000 | 0.00000 |
| 25 | 135 | 0.05000 | 0.00500 | 0.00000 |
| 25 | 180 | 0.02500 | 0.00250 | 0.00000 |

Table D2 - Operational Profile: Cargo Ship

| | | Significant Wave Height (meters) | | |
|---|---|---|---|---|
| Speed (kts) | Heading | 0 - 5 | 6 - 10 | > 10 |
| 5 | 0 | 0.01000 | 0.12500 | 0.17500 |
| 5 | 45 | 0.02000 | 0.12500 | 0.17500 |
| 5 | 90 | 0.02000 | 0.06250 | 0.08750 |
| 5 | 135 | 0.02000 | 0.12500 | 0.17500 |
| 5 | 180 | 0.01000 | 0.06250 | 0.08750 |
| 15 | 0 | 0.11500 | 0.12500 | 0.07500 |
| 15 | 45 | 0.23000 | 0.12500 | 0.07500 |
| 15 | 90 | 0.23000 | 0.06250 | 0.03750 |
| 15 | 135 | 0.23000 | 0.12500 | 0.07500 |
| 15 | 180 | 0.11500 | 0.06250 | 0.03750 |

Table D3 - Operational Profile: Aircraft Carrier

| | | Significant Wave Height (meters) | | |
|---|---|---|---|---|
| Speed (kts) | Heading | 0 - 5 | 6 - 10 | > 10 |
| 5 | 0 | 0.01000 | 0.12500 | 0.17500 |
| 5 | 45 | 0.02000 | 0.12500 | 0.17500 |
| 5 | 90 | 0.02000 | 0.06250 | 0.08750 |
| 5 | 135 | 0.02000 | 0.12500 | 0.17500 |
| 5 | 180 | 0.01000 | 0.06250 | 0.08750 |
| 15 | 0 | 0.09600 | 0.11500 | 0.07500 |
| 15 | 45 | 0.19200 | 0.11500 | 0.07500 |
| 15 | 90 | 0.19200 | 0.05750 | 0.03750 |
| 15 | 135 | 0.19200 | 0.11500 | 0.07500 |
| 15 | 180 | 0.09600 | 0.05750 | 0.03750 |
| 25 | 0 | 0.01900 | 0.01000 | 0.00000 |
| 25 | 45 | 0.03800 | 0.01000 | 0.00000 |
| 25 | 90 | 0.03800 | 0.00500 | 0.00000 |
| 25 | 135 | 0.03800 | 0.01000 | 0.00000 |
| 25 | 180 | 0.01900 | 0.00500 | 0.00000 |

Table D4 - Operational Profile: 30-60 headings, 5-15-25 speeds

| | | Significant Wave Height (meters) | | |
|---|---|---|---|---|
| Speed (kts) | Heading | 0 - 5 | 6 - 10 | > 10 |
| 5 | 0 | 0.00417 | 0.01400 | 0.08000 |
| 5 | 30 | 0.00833 | 0.03850 | 0.16000 |
| 5 | 60 | 0.00833 | 0.02450 | 0.04000 |
| 5 | 90 | 0.00833 | 0.01050 | 0.00000 |
| 5 | 120 | 0.00833 | 0.01050 | 0.00000 |
| 5 | 150 | 0.00833 | 0.02800 | 0.08000 |
| 5 | 180 | 0.00417 | 0.01400 | 0.04000 |
| 15 | 0 | 0.01667 | 0.06600 | 0.12000 |
| 15 | 30 | 0.03333 | 0.18150 | 0.24000 |
| 15 | 60 | 0.03333 | 0.11550 | 0.06000 |
| 15 | 90 | 0.03333 | 0.04950 | 0.00000 |
| 15 | 120 | 0.03333 | 0.04950 | 0.00000 |
| 15 | 150 | 0.03333 | 0.13200 | 0.12000 |
| 15 | 180 | 0.01667 | 0.06600 | 0.06000 |
| 25 | 0 | 0.06250 | 0.02000 | 0.00000 |
| 25 | 30 | 0.12500 | 0.05500 | 0.00000 |
| 25 | 60 | 0.12500 | 0.03500 | 0.00000 |
| 25 | 90 | 0.12500 | 0.01500 | 0.00000 |
| 25 | 120 | 0.12500 | 0.01500 | 0.00000 |
| 25 | 150 | 0.12500 | 0.04000 | 0.00000 |
| 25 | 180 | 0.06250 | 0.02000 | 0.00000 |

Table D5 - Operational Profile: Combatant - integrated

| | | Significant Wave Height (meters) | | |
|---|---|---|---|---|
| Speed (kts) | Heading | 0 - 5 | 6 - 10 | > 10 |
| 5 | 0 | 0.04100 | 0.07600 | 0.06000 |
| 5 | 45 | 0.08200 | 0.08400 | 0.76000 |
| 5 | 89 | 0.08200 | 0.02750 | 0.00000 |
| 5 | 135 | 0.08200 | 0.05400 | 0.03000 |
| 5 | 179 | 0.04100 | 0.03300 | 0.00000 |
| 15 | 0 | 0.07100 | 0.11600 | 0.00000 |
| 15 | 45 | 0.14300 | 0.28700 | 0.09200 |
| 15 | 89 | 0.14300 | 0.04550 | 0.00000 |
| 15 | 135 | 0.14300 | 0.11500 | 0.00800 |
| 15 | 179 | 0.07100 | 0.06000 | 0.05000 |
| 25 | 0 | 0.01300 | 0.00700 | 0.00000 |
| 25 | 45 | 0.02500 | 0.01900 | 0.00000 |
| 25 | 89 | 0.02500 | 0.01900 | 0.00000 |
| 25 | 135 | 0.02500 | 0.01900 | 0.00000 |
| 25 | 179 | 0.01300 | 0.03800 | 0.00000 |

Table D6 - Operational Profile: Amphibious or Fast Cargo - integrated

| | | Significant Wave Height (meters) | | |
|---|---|---|---|---|
| Speed (kts) | Heading | 0 - 5 | 6 - 10 | > 10 |
| 5 | 0 | 0.03800 | 0.04800 | 0.22900 |
| 5 | 45 | 0.07500 | 0.08200 | 0.25700 |
| 5 | 90 | 0.07500 | 0.05500 | 0.08450 |
| 5 | 135 | 0.07500 | 0.06700 | 0.11400 |
| 5 | 180 | 0.03800 | 0.03400 | 0.05700 |
| 15 | 0 | 0.08500 | 0.15200 | 0.05700 |
| 15 | 45 | 0.17000 | 0.21000 | 0.08600 |
| 15 | 90 | 0.17000 | 0.12400 | 0.02950 |
| 15 | 135 | 0.17000 | 0.13800 | 0.05700 |
| 15 | 180 | 0.08500 | 0.07000 | 0.02900 |
| 25 | 0 | 0.00200 | 0.00300 | 0.00000 |
| 25 | 45 | 0.00500 | 0.00500 | 0.00000 |
| 25 | 90 | 0.00500 | 0.00500 | 0.00000 |
| 25 | 135 | 0.00500 | 0.00500 | 0.00000 |
| 25 | 180 | 0.00200 | 0.00200 | 0.00000 |

Table D7 - Operational Profile: Carrier - integrated

| | | Significant Wave Height (meters) | | |
|---|---|---|---|---|
| Speed (kts) | Heading | 0 - 5 | 6 - 10 | > 10 |
| 5 | 0 | 0.05000 | 0.04800 | 0.15000 |
| 5 | 45 | 0.10300 | 0.19600 | 0.36800 |
| 5 | 90 | 0.10300 | 0.16000 | 0.05600 |
| 5 | 135 | 0.10300 | 0.09400 | 0.08000 |
| 5 | 180 | 0.05000 | 0.03000 | 0.01200 |
| 15 | 0 | 0.05600 | 0.04700 | 0.07500 |
| 15 | 45 | 0.11300 | 0.11800 | 0.11500 |
| 15 | 90 | 0.11300 | 0.11400 | 0.02800 |
| 15 | 135 | 0.11300 | 0.07200 | 0.07800 |
| 15 | 180 | 0.05600 | 0.02500 | 0.03800 |
| 25 | 0 | 0.01800 | 0.00800 | 0.00000 |
| 25 | 45 | 0.03500 | 0.01500 | 0.00000 |
| 25 | 90 | 0.03500 | 0.02900 | 0.00000 |
| 25 | 135 | 0.03500 | 0.03600 | 0.00000 |
| 25 | 180 | 0.01800 | 0.00800 | 0.00000 |

Table D8 - Operational Profile: Auxiliary or Slow Cargo - integrated

| | | Significant Wave Height (meters) | | |
|---|---|---|---|---|
| Speed (kts) | Heading | 0 - 5 | 6 - 10 | > 10 |
| 5 | 0 | 0.02500 | 0.03500 | 0.17500 |
| 5 | 45 | 0.05000 | 0.07500 | 0.17500 |
| 5 | 90 | 0.05000 | 0.05100 | 0.08700 |
| 5 | 135 | 0.05000 | 0.04200 | 0.17500 |
| 5 | 180 | 0.02500 | 0.01300 | 0.08800 |
| 15 | 0 | 0.10000 | 0.14900 | 0.07500 |
| 15 | 45 | 0.20000 | 0.20000 | 0.07500 |
| 15 | 90 | 0.20000 | 0.18500 | 0.03700 |
| 15 | 135 | 0.20000 | 0.17500 | 0.07500 |
| 15 | 180 | 0.10000 | 0.07500 | 0.03800 |

Table D9 - Operational Profile: Combatant - Michaelson

| Speed (kts) | Heading | Significant Wave Height (meters) 0 - 3 | 4 - 6 | > 6 |
|---|---|---|---|---|
| 5 | 1 | 0.06884 | 0.06131 | 0.11111 |
| 5 | 45 | 0.09032 | 0.09045 | 0.08642 |
| 5 | 90 | 0.06641 | 0.04422 | 0.08642 |
| 5 | 135 | 0.07458 | 0.04422 | 0.02469 |
| 5 | 180 | 0.04791 | 0.02714 | 0.02469 |
| 15 | 1 | 0.10590 | 0.14975 | 0.16049 |
| 15 | 45 | 0.15724 | 0.19698 | 0.16049 |
| 15 | 90 | 0.10414 | 0.13970 | 0.09877 |
| 15 | 135 | 0.13127 | 0.09447 | 0.08642 |
| 15 | 180 | 0.07297 | 0.06131 | 0.04938 |
| 25 | 1 | 0.01583 | 0.01809 | 0.00000 |
| 25 | 45 | 0.02168 | 0.02714 | 0.01235 |
| 25 | 90 | 0.01473 | 0.01307 | 0.02469 |
| 25 | 135 | 0.01815 | 0.02412 | 0.01235 |
| 25 | 180 | 0.01004 | 0.00804 | 0.06173 |

Table D10 - Operational Profile: Amphibious or Fast Cargo - Michaelson

| Speed (kts) | Heading | Significant Wave Height (meters) 0 - 3 | 4 - 6 | > 6 |
|---|---|---|---|---|
| 5 | 0 | 0.06345 | 0.06341 | 0.05714 |
| 5 | 45 | 0.10554 | 0.08696 | 0.08571 |
| 5 | 90 | 0.07840 | 0.03261 | 0.05714 |
| 5 | 135 | 0.08544 | 0.03442 | 0.05714 |
| 5 | 180 | 0.04984 | 0.02174 | 0.02857 |
| 15 | 0 | 0.11891 | 0.16304 | 0.22857 |
| 15 | 45 | 0.17500 | 0.27899 | 0.25714 |
| 15 | 90 | 0.10585 | 0.12681 | 0.05714 |
| 15 | 135 | 0.13125 | 0.12681 | 0.11429 |
| 15 | 180 | 0.07650 | 0.03804 | 0.05714 |
| 25 | 0 | 0.00174 | 0.01268 | 0.00000 |
| 25 | 45 | 0.00190 | 0.01087 | 0.00000 |
| 25 | 90 | 0.00190 | 0.00000 | 0.00000 |
| 25 | 135 | 0.00269 | 0.00000 | 0.00000 |
| 25 | 180 | 0.00158 | 0.00362 | 0.00000 |

Table D11 - Operational Profile: Carrier - Michaelson

| | | Significant Wave Height (meters) | | |
|---|---|---|---|---|
| Speed (kts) | Heading | 0 - 3 | 4 - 6 | > 6 |
| 5 | 0 | 0.07428 | 0.10083 | 0.03846 |
| 5 | 45 | 0.11625 | 0.09991 | 0.30769 |
| 5 | 90 | 0.08851 | 0.08973 | 0.11538 |
| 5 | 135 | 0.09484 | 0.06383 | 0.07692 |
| 5 | 180 | 0.05235 | 0.04625 | 0.00000 |
| 15 | 0 | 0.07585 | 0.06846 | 0.03846 |
| 15 | 45 | 0.12624 | 0.15171 | 0.11538 |
| 15 | 90 | 0.09001 | 0.11193 | 0.15385 |
| 15 | 135 | 0.09321 | 0.07031 | 0.03846 |
| 15 | 180 | 0.05196 | 0.06105 | 0.00000 |
| 25 | 0 | 0.02285 | 0.01943 | 0.00000 |
| 25 | 45 | 0.03721 | 0.03608 | 0.00000 |
| 25 | 90 | 0.02728 | 0.04163 | 0.07692 |
| 25 | 135 | 0.03055 | 0.02405 | 0.03846 |
| 25 | 180 | 0.01860 | 0.01480 | 0.00000 |

Table D12 - Operational Profile: Auxiliary or Slow Cargo - Michaelson

| | | Significant Wave Height (meters) | | |
|---|---|---|---|---|
| Speed (kts) | Heading | 0 - 3 | 4 - 6 | > 6 |
| 5 | 0 | 0.04278 | 0.05491 | 0.04938 |
| 5 | 45 | 0.06082 | 0.04439 | 0.11111 |
| 5 | 90 | 0.04243 | 0.03271 | 0.02469 |
| 5 | 135 | 0.04486 | 0.03271 | 0.03704 |
| 5 | 180 | 0.03393 | 0.02220 | 0.00000 |
| 15 | 0 | 0.15471 | 0.19042 | 0.19753 |
| 15 | 45 | 0.20694 | 0.26636 | 0.19753 |
| 15 | 90 | 0.14620 | 0.13318 | 0.18519 |
| 15 | 135 | 0.15957 | 0.14836 | 0.14815 |
| 15 | 180 | 0.10777 | 0.07477 | 0.04938 |